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Study on Vibration Isolation Design of Dual Piezoelectric Cooling Jets

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Abstract: The traditional cooling fans can't be applied in modern consumer electronic products because the modern electronic products always have slim shapes. In recent years, GE's Dual Piezoelectric Cooling Jets (DCJ) constructed by piezoelectricity materials had been developed and employed in modern electronic products' cooling. The main cooling principle of DCJ is utilizing variation of heat field which is conducted by vibration to accomplish heat exchange. However, the vibration generated by DCJ will be transmitted to adjacent devices and cause the extra vibration problems.

Appropriate glue and isolated damper; like rubber and cohesive polymer; can reduce the transmission of vibration. Glue is applied to bond the adjacent piezo thin plates, and isolated damped is applied to fasten DCJ on the base of electronic products. In this study, the numerical simulation package ANSYS is utilized to simulate the vibration reduction effects of various kinds of glue and isolated dampers. Furthermore, the simulation results are also employed to confirm the better isolated types that can isolate the extra vibration effectively.

Keyword: Dual Piezoelectric Cooling Jets (DCJ), Numerical simulation

1. Introduction

With the advance on thinning tendency of electronic products, the development of precise cooling machinery becomes very important and imperative. Piezoelectric ceramics is an intelligent material that has been applied widely in various fields. Because of the advantages of light-weight, low power consumption, high stability and easily control, piezoelectric ceramics becomes the common material of active control. In recent years, piezoelectric material were also generally employed as an actuator and employed to cause vibration independently.

Miniaturization of precise machinery caused the normal cooling fans can't be assembled. Dual piezoelectric cooling jets (DCJ) is a new cooling system and utilize piezoelectric vibration to achieve heat exchange. The vibration amplitude and frequency are controlled by electric current variation. However, the piezoelectric vibration is always transmitted to the adjacent devices and caused the dispensable vibration and extra noise. In this study, we chose the different adhesives to ease the transmission of piezoelectric vibration and employ numerical simulation package ANSYS to confirm the accuracy.

Finite element method, numerical analysis and experimentation were usually used to confirm the active control characteristics of piezoelectric materials. ANSYS is an appropriate software that can be used to simulate the DCJ vibration. In this study, the piezoelectric coupling element SOLID-5 is used to simulate the actuated piezoelectric sheets and SOLID-45 element is used to simulate the vibrated thin metals and adhesives. First, we employ harmonic analysis to find the specific frequency between 100 and 200 Hz that will produce the appropriate vibration amplitude. The lower frequency and smaller amplitude always caused the bad heat exchange efficiency. According to simulated results and actual use, 150 Hz is a suggested frequency.

The relative references about applications of DCJ are reviewed briefly as follows. Xu [1] focused on smart structures that can execute active control and simulated the vibration modes caused by piezoelectric ceramics. Becker etc. [2]

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employed ANSYS and MATLAB to discuss the vibration reduction of host machine that connected by piezoelectric shunt and passive circuits. Nguyen [3] adhered piezoelectric ceramics to a cantilever beam and connected R-L shunt circuit damping, and tried to find the optimum vibration frequency. Sui [4] designed a piezoelectric actuator and confirmed that piezoelectric actuator can isolate vibration at least 80%. Jang [5] employed numerical analysis method to simulate the aero dynamics of new DCJ.

2. Finite element model

2.1 Dual piezoelectric cooling jets

Dual piezoelectric cooling jets are composed of PZT and two nickel-iron thin plates, and the PZT is pasted to nickel-iron plate individually. The traditional design of DCJ was using viscoelastic glue to constrain two nickel-iron plates. DCJ and foundation supports are connected by viscoelastic glue and formed a fluctuated machinery. Fig. 1 shows the DCJ's conformation.

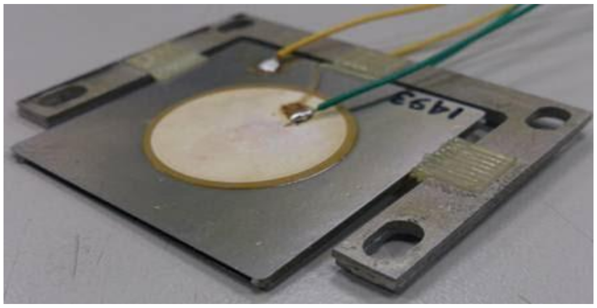

Fig.1 Dual piezoelectric cooling jets (DCJ)

ANSYS is use to simulate the vibration characteristics and the finite element model of DCJ established in this study is according to traditional design of DCJ machinery. The dimensions of nickel-iron plate is 4cm×4cm, and thickness is 0.011cm. The radius of PZT is 1.25cm, and thickness is also 0.011cm. The distance between two nickel-iron plates is 0.1cm.

2.2 Elements and materials

The elements chosen in this study is Solid-45 and Solid-5. Solid-45 is a three dimension element with 8 nodes and can be used to simulate the nickel-iron plate, foundation and viscoelastic glue. Solid-5 is a 3-D piezoelectric coupling element that always used to simulate the PZT.

Foundation material considered in this study is PE. PE is a common and light material that is suitable for foundation design. Besides, the material of DCJ plates is nickel-iron. Table 1 shows the material parameters of nickel-iron plate.

Table 1 Nickel-iron material parameters

	Young's Modulus(N/m^2)	Poisson Ratio	Density(kg/m^3)
Nickel-iron	200	0.29	7850

The standard viscoelastic glue used in this study is 3M ISD-112. 3M ISD-112 frequently used to isolate the high frequency vibration. Table 2 shows the related material parameters.

Table 2 Viscoelastic material parameters

Material	3M ISD-112
Young's Modulus(N/m^2)	5.51×10^7
Poisson Ratio	0.45
Density(kg/m^3)	980
Loss Factor (120~180Hz, 25℃)	0.9

The different damping of viscoelastic glue will affect the vibration modes and transmissions. ANSYS used Rayleigh damping to define the damping parameter.

$$[C] = \alpha_R[M] + \beta_R[K]$$

The factor α_R is mass proportional damping coefficient and β_R is stiffness proportional damping coefficient. The mass effect can be ignored in this study, so α_R is regarded as zero. The other factor β_R is related to viscoelastic damping, and can be expressed as $\beta_R = \eta/\omega_n$. The symbol η is loss factor and ω_n is natural frequency.

Piezoelectric ceramics employed in this study is PZT-5H. Table 3 shows the parameters.

Table 3 Material parameters of piezoelectric ceramics

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Piezoelectric ceramics PZT-5H	
Density(kg/m^3)	7500
Stiffness matrix (GPa)	$[c]_{6\times6}=\begin{bmatrix}126 & 79.5 & 84.1 & 0 & 0 & 0\\ 0 & 126 & 84.1 & 0 & 0 & 0\\ 0 & 0 & 117 & 0 & 0 & 0\\ 0 & 0 & 0 & 23.3 & 0 & 0\\ 0 & 0 & 0 & 0 & 23.3 & 0\\ 0 & 0 & 0 & 0 & 0 & 23.3\end{bmatrix}$
Stress matrix (C/m^2)	$[e]_{6\times3}=\begin{bmatrix}0 & 0 & -6.5\\ 0 & 0 & -6.5\\ 0 & 0 & 23.3\\ 0 & 17 & 0\\ 17 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}$
Dielectric matrix	$[e]_{3\times3}=\begin{bmatrix}1.503\times10^{-8} & 0 & 0\\ 0 & 1.503\times10^{-8} & 0\\ 0 & 0 & 1.503\times10^{-8}\end{bmatrix}$

2.3 Harmonic analysis

In order to achieve effective heat-exchange and cooling, the vibration amplitude of DCJ must be large enough. However, the obvious vibration amplitude will cause extra vibration and communicate to foundations. Harmonic analysis can help us to find the vibration amplitude of each frequency and provide the information to choose the appropriate vibration frequency. Fig.2 shows the harmonic analysis model, and the purple areas are the fixed boundaries.

According to actual operating conditions, the frequency range of harmonic analysis is considered since 100Hz to 200Hz and the input voltage is 5V. The record positions are center, front-end and side of DCJ individually. Fig.3 shows the record positions.

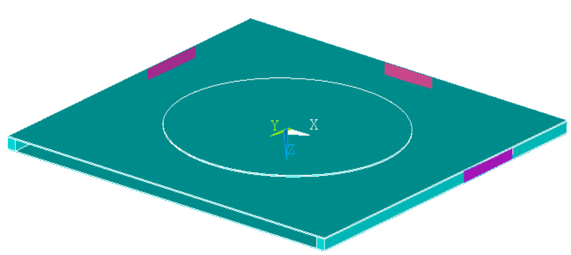


Fig.2 Harmonic analysis model

The harmonic analysis results are displayed in Fig.4. According to the amplitude-frequency relations, we can find the maximum vibration amplitudes almost appear at the front-end of DCJ. Furthermore, the bigger amplitudes corresponded to variant frequency are discussed. In Fig.4, the bigger amplitudes appear at 121Hz, 144Hz, 150Hz, 176Hz, 186Hz and 198Hz. After the appropriate estimate, the vibration frequency 150Hz is suggested to employ in DCJ design. Actually, the commonly used frequency of DCJ is about 150Hz.

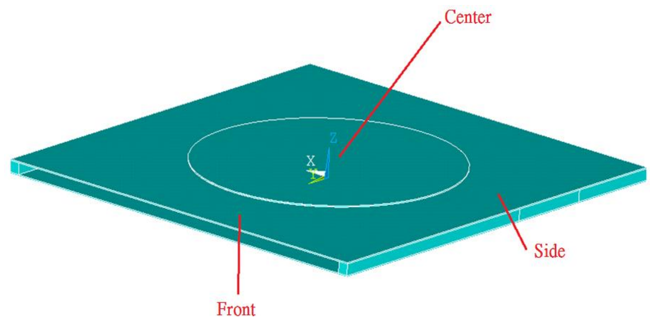


Fig.3 Amplitude record positions of harmonic analysis

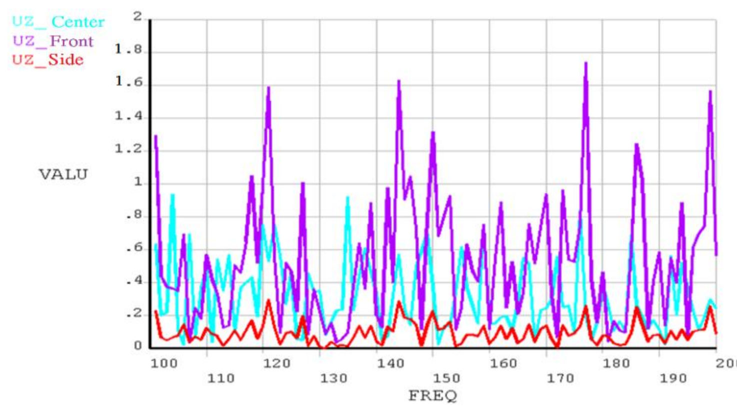


Fig.4 Amplitude-frequency relations

3. Simulation results and discussion

Transient response analysis is used to simulate the vibration amplitude of DCJ and vibration transmission of viscoelastic glue. Vibration frequency is set as 150Hz, and the maximum amplitude of nickel-iron plate is 0.5mm. Fig.5 shows the boundary conditions. The purple areas at four corners are fixed ends.

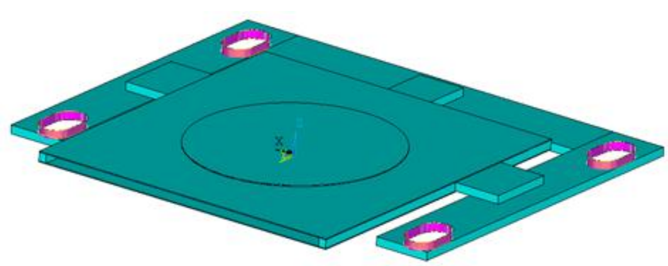


Fig.5 Boundary conditions of full model

Viscoelastic damping variation is employed to isolate vibration transmission in this study, and Rayleigh damping is considered. The loss factor of 3M ISD-112 is 0.9, so β_R can be expressed as 0.006. Furthermore, we assume the other two β_R are 0.003 and 0.009 individually. The vibration amplitude measured position is present in Fig.6.

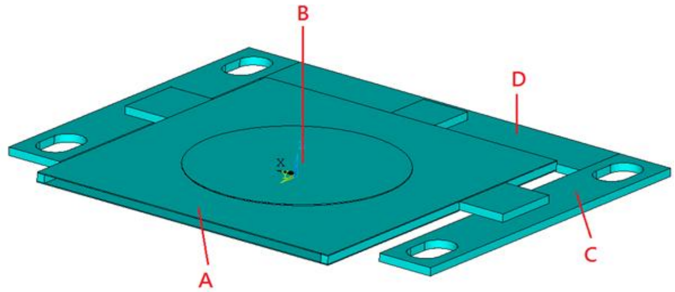


Fig.6 Vibration amplitude measured positions

Simulation result shows that the front-end of DCJ will appear open-close situation, and the vibration mode is independent of damping. Fig.7 shows the vibration mode and amplitude of DCJ.

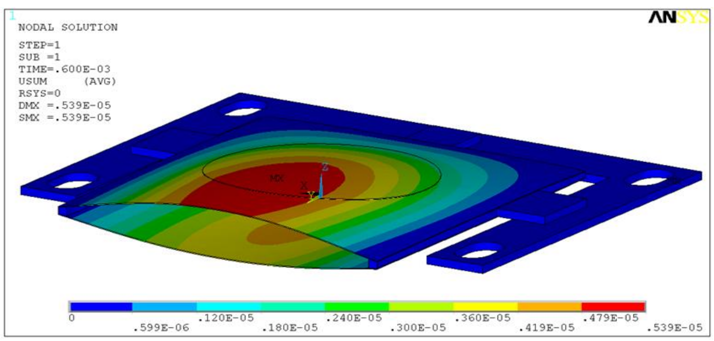
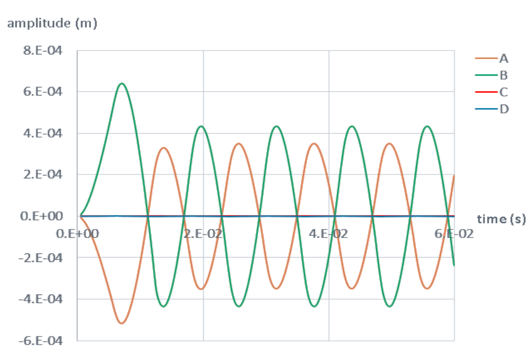


Fig.7 Vibration mode of DCJ

For β_R=0.003 case, the vibration amplitude measured at the four positions are displayed in Fig.8. The maximum amplitude is appeared at front-end of DCJ, and vibration transmits to foundation will decay to $\pm 1 \times 10^{-7}$ m.



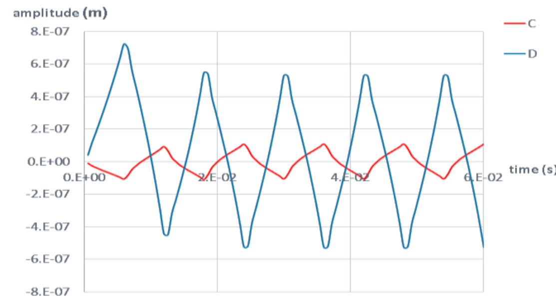


Fig.8 β_R=0.003, vibration amplitude

For β_R=0.006 case, it's the actual factor of 3M ISD-112. The simulation result shows that the maximum amplitude of four measured positions are smaller than the β_R=0.003 case. It seems that damping is effective in isolating the vibration. Fig.9 shows the vibration amplitude of β_R=0.006 case.

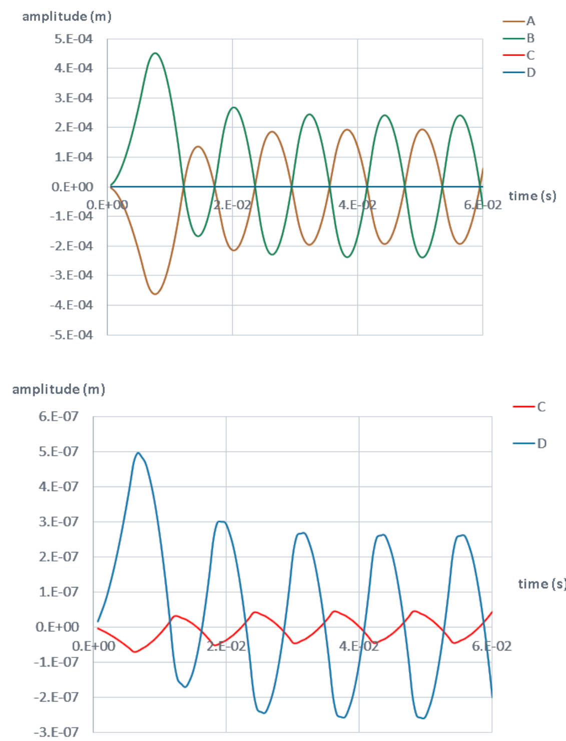


Fig.9 β_R=0.006, vibration amplitude

For β_R =0.009 case, the maximum amplitude of four measured positions appears obvious reduction than β_R=0.006 case. Especially in foundation, the transmitted vibration compared with β_R=0.006 case appears about 33% reduction. Fig.10 show the vibration amplitude of β_R=0.009 case.

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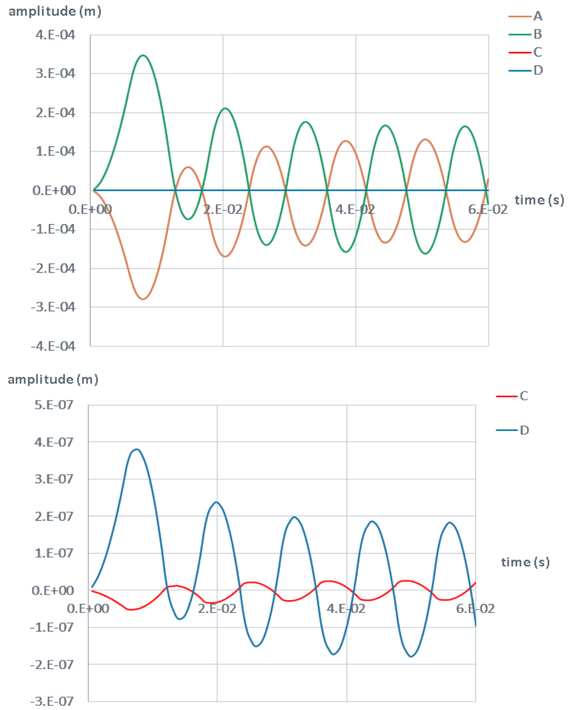
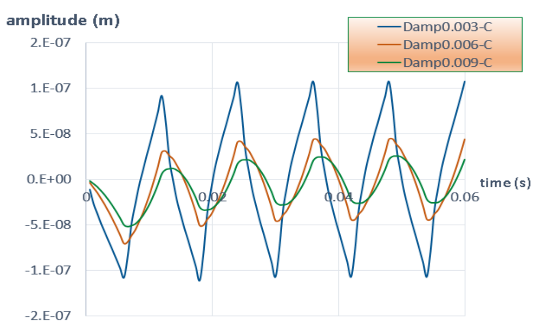
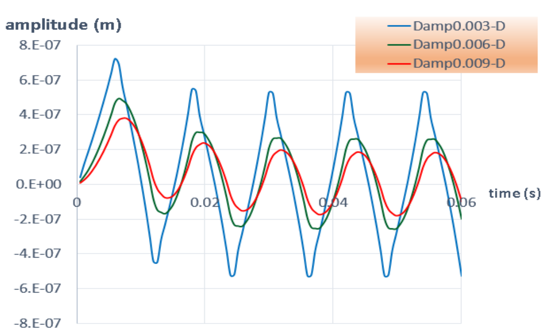


Fig.10 β_R=0.009, vibration amplitude

Finally, we compared the vibration amplitudes measured at foundation. Both point-C and point-D show the same tendency, the vibration isolated is effective with the increasing damping.



measured point-C



measured point-D

Fig.11 Vibration amplitude comparisons

4. Conclusion

The vibration isolated effects of different damping is discussed in this study. Furthermore, ANSYS is used to simulate the vibration conditions and confirmed that viscoelastic glue is indeed effective when its loss factor is large enough. According to simulation results, the isolated efficiency increasing tendency is nonlinear with increasing damping. This result shows that viscoelastic glue can isolate DCJ vibration, but it has a limit.

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